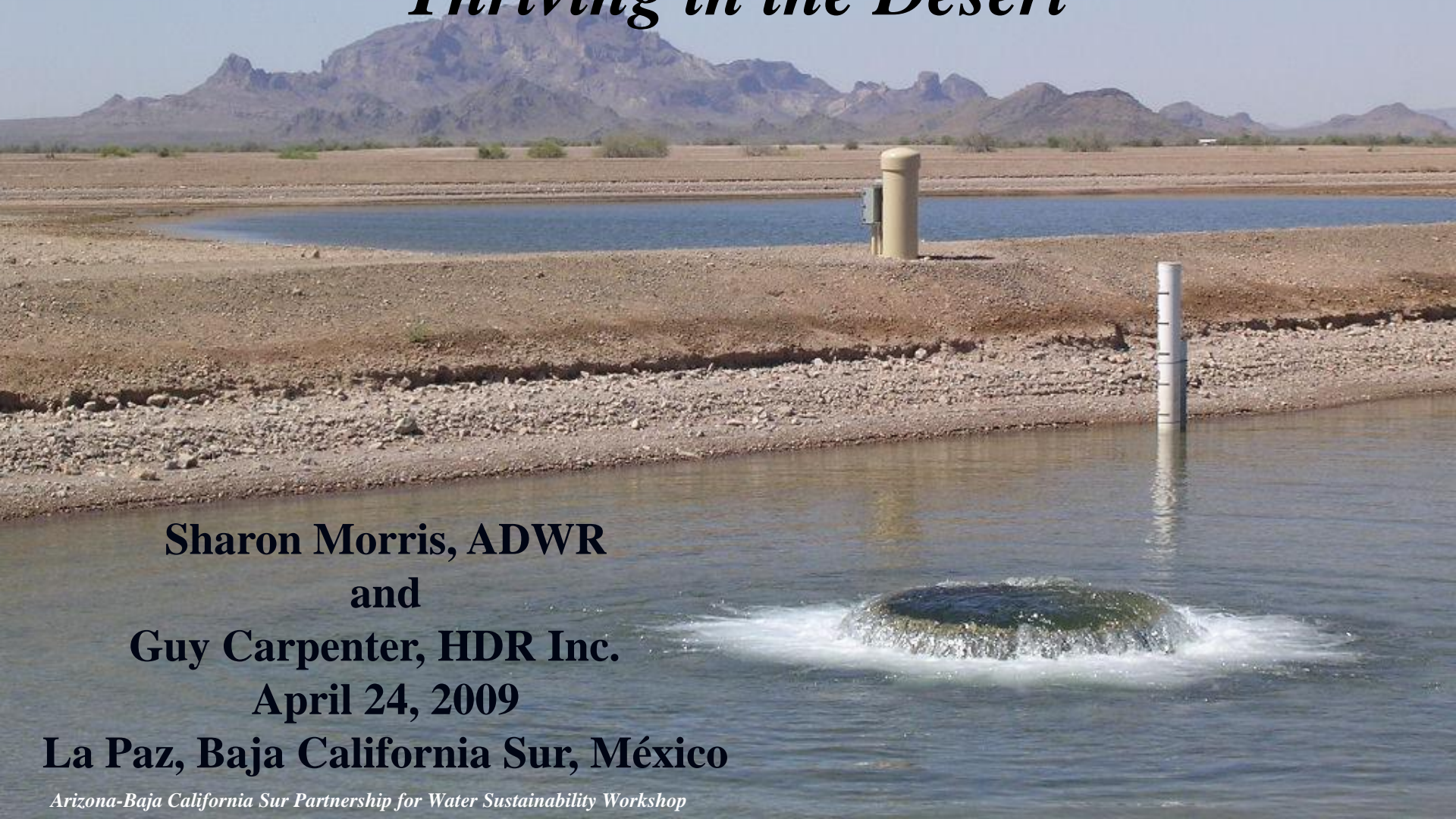


Aquifer Recharge Experiences and Technologies: *Thriving in the Desert*



**Sharon Morris, ADWR
and**

Guy Carpenter, HDR Inc.

April 24, 2009

La Paz, Baja California Sur, México

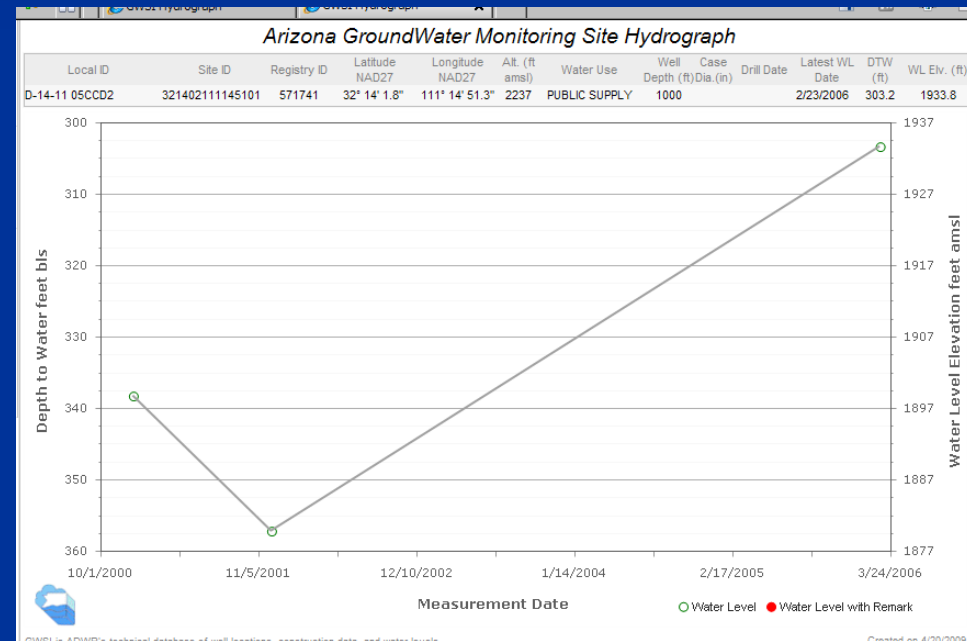
Arizona-Baja California Sur Partnership for Water Sustainability Workshop

Topics

- 💧 **Managed Aquifer Recharge (MAR) defined**
 - ✦ **Types of water stored**
- 💧 **Basic Methodology**
- 💧 **Regulatory Process**
- 💧 **Case Studies**
- 💧 **Reclaimed Water**
- 💧 **Planning Considerations**
- 💧 **Management Tools**

What is Managed Aquifer Recharge?

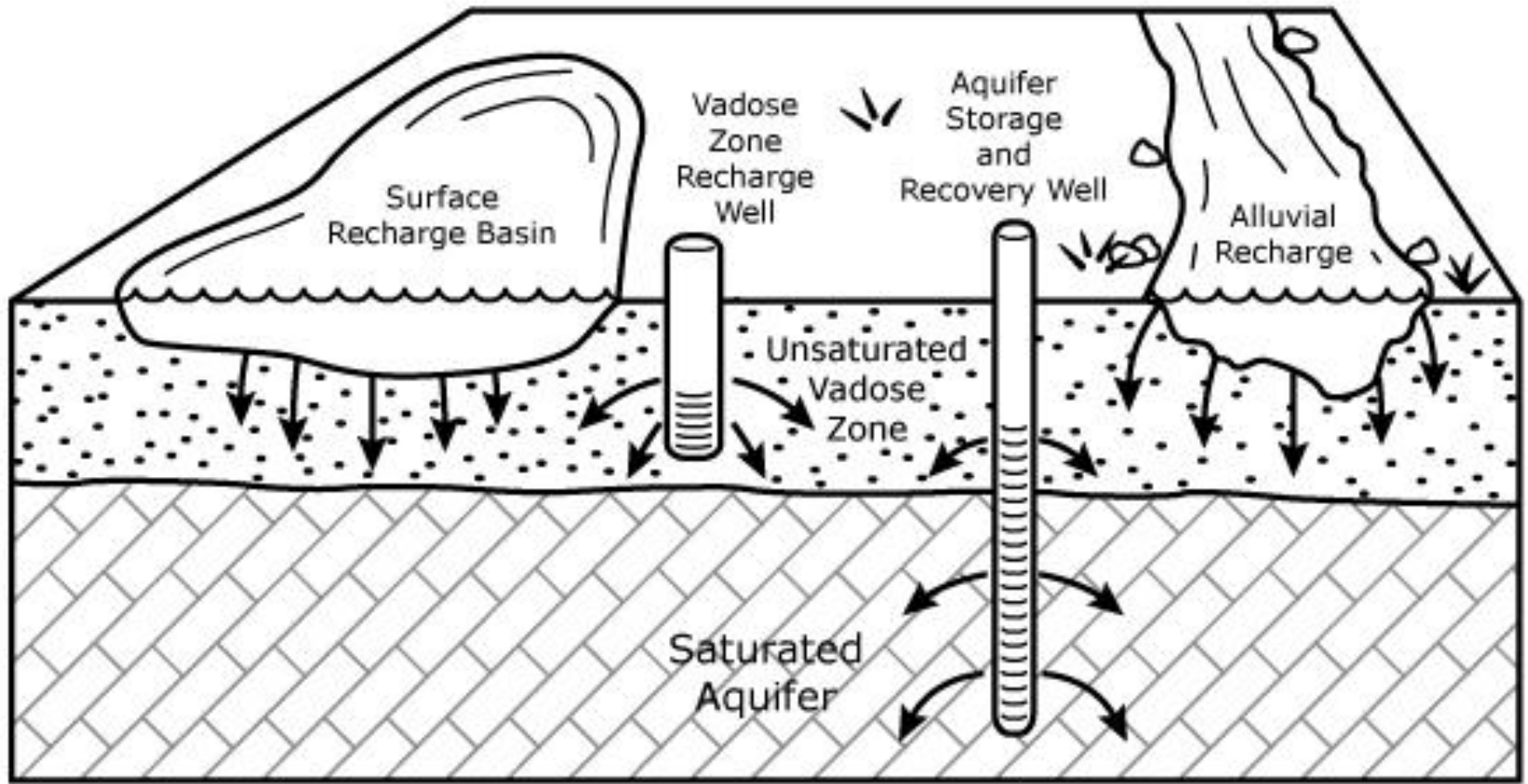
- 💧 Replenishment of an aquifer
- 💧 Storage
- 💧 Mitigation tool
- 💧 Water sources:
 - ☞ Treated Wastewater
 - ☞ Surface Water
 - ☞ Storm water



<https://gisweb.azwater.gov/waterresourcedata/>

Recharge Methods

Groundwater Recharge Methods

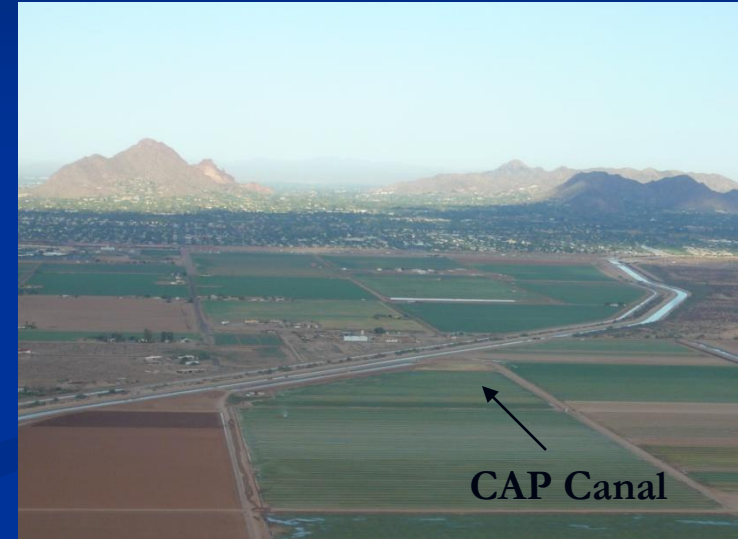


Arizona's Regulatory Process

- 💧 1986 - Underground Storage and Recovery Act
- 💧 1994 - Underground Water Storage, Savings and Replenishment Program (Recharge Program)
- 💧 2004 - Hydrologic Guidelines
- 💧 Underground Storage Facility (USF) Permits
- 💧 River Channel and Constructed facility permits
 - ✦ Maximum permit duration = 20 years

River Channel Underground Storage Facility (USF)

- 💧 Natural river course
- 💧 Without constructed devices
- 💧 Source waters
 - ✦ Treated Wastewater
 - ✦ River Water / CAP Water
 - ✦ Cannot store waters naturally present in river channel



Constructed Underground Storage Facility (USF)

- 💧 Substantial construction involved
 - ⚡ Vadose zone recharge wells
 - ⚡ ASR wells
 - ⚡ Recharge basins
 - ⚡ Trenches
 - ⚡ Berms
- 💧 Source waters: treated wastewater, CAP, surface water

Incentives for Recharge

- 💧 Store when water available, withdraw during drought
- 💧 Storage and reuse of effluent
- 💧 Earn credits for storing, similar to a bank account
 - ✦ 5% of water stored reserved for the aquifer
- 💧 Water providers are able to comply with Arizona's groundwater replenishment requirements
- 💧 Mitigation of groundwater mining and effects on riparian habitats (federal and state regulations)

USF Permitting Process

💧 Applications reviewed and permitted by ADWR

- ✦ Type of facility
- ✦ Facility design
- ✦ Compliance with other state and federal regulatory agencies
- ✦ Must demonstrate capacity to store full requested volume



USF Hydrologic Report

- 💧 Facility design and characteristics
 - ✦ Type of source water
 - ✦ Facility monitoring
 - ✦ Contingency plans
- 💧 Study area hydrogeology
 - ✦ Characterization of the vadose zone and aquifer
 - ✦ Historic and current water levels and trends
 - ✦ Required groundwater modeling

USF Hydrologic Report

💧 Hydrologic feasibility

- ✦ Groundwater mound and area of impact (AOI)
- ✦ Lateral extent of projected 1-foot water-level rise
- ✦ Groundwater model

💧 No unreasonable harm

- ✦ Inventory of existing land and water uses within AOI (ie landfills, mining operations)
- ✦ Water quality analysis
- ✦ Monitoring plan and alert levels

💧 Facility operation and maintenance

Sand and Gravel Mine Unreasonable Harm Example



An Overview of Arizona Recharge

- 💧 Tour of Select Recharge Facilities and Methodologies throughout Arizona
- 💧 Tonopah Facility Overview
- 💧 Trends for Arizona Recharge

Arizona Recharge Numbers

- 💧 67 active Underground Storage Facilities (USFs)
- 💧 7 River Channel / 60 Constructed
- 💧 Permitted volumes range from 8.1×10^4 to 2.4×10^8 m³ /year (67 to 200,000 acre-feet/year)
- 💧 Largest recharged volume in one year = 1.8×10^8 m³ /year (143,000 acre-feet)
- 💧 Over 3×10^9 m³ (2.5 million acre-feet) stored to date

Arizona and Baja California Sur



Map of Arizona

Active Management Areas (AMAs)

Urban areas with requirements that limit the over use by municipal and agricultural of groundwater in an attempt to reach “safe yield” by 2025.



River Channel Recharge Projects

- 💧 Relatively low cost with minimal construction
- 💧 Recharge only applicable within facility length
- 💧 Natural flows not applicable to recharge
- 💧 Evapotranspiration and evaporation losses
- 💧 7 river channel facilities statewide

Lower Santa Cruz River Channel USF



Lower Santa Cruz River Channel USF

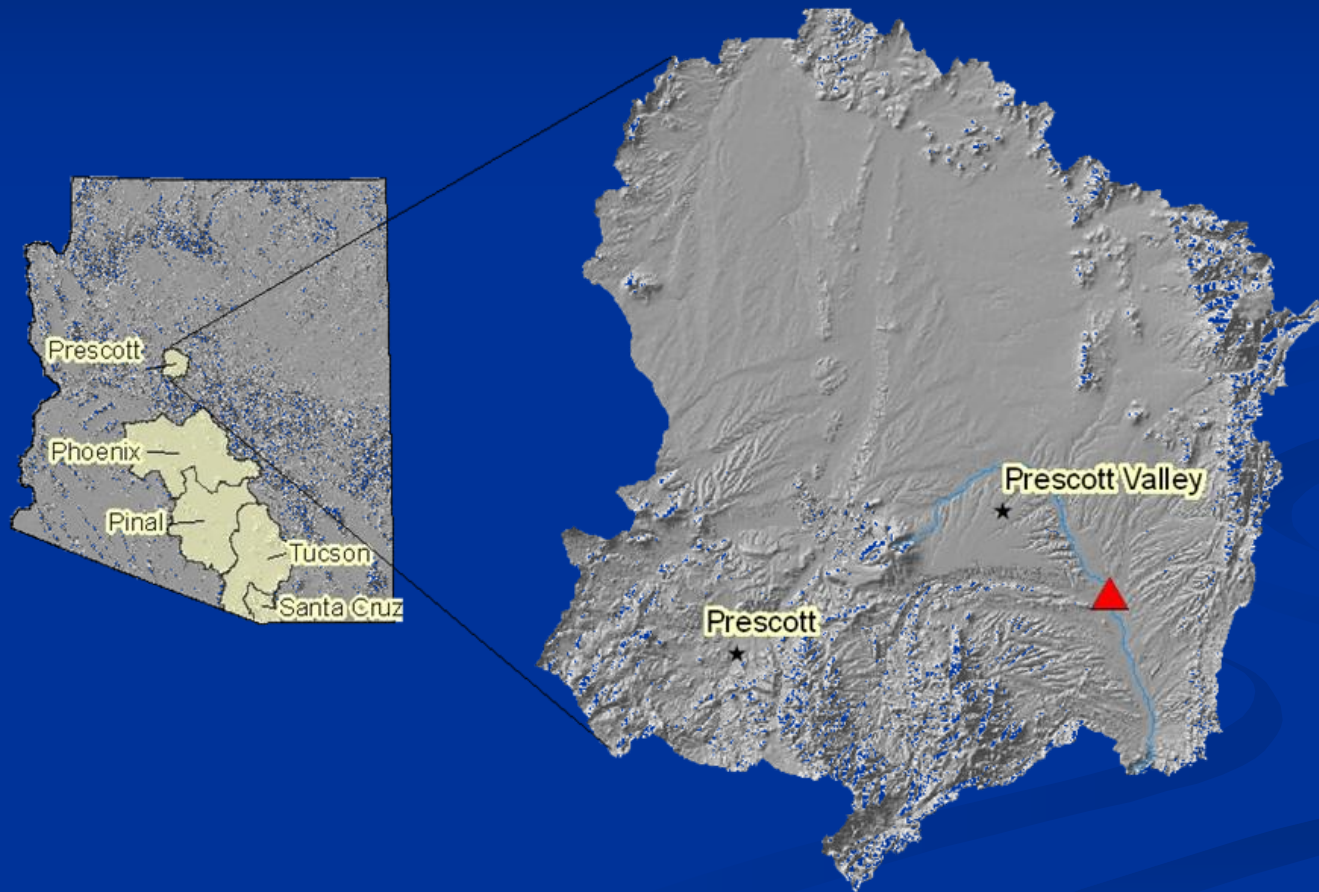
- 5.2 x 10⁷ m³ /year (43,000 acre-feet/year)
- Effluent source water
- Santa Cruz River channel
- Facility Length 29 km (17.9 miles)
- Infiltration higher after storm events
- Accounting for ET loss
- 2007 recharged 21,042 acre-feet



In-Channel Constructed USF

- 💧 **Modification of river channel**
 - ✦ constructed berms and/or in-channel trenches used to decrease flow rates and increase infiltration rates
- 💧 **Loss of infiltration during high flow events or berm outage**

Prescott Valley USF



Prescott Valley USF



- 💧 $6.2 \times 10^6 \text{ m}^3$ /year
(5,150 acre-feet/year)
- 💧 ~7.2 km (4.5 miles)
in length
- 💧 Effluent source
water
- 💧 Upper Agua Fria
River Channel
- 💧 No recharge during
storm events
- 💧 2007 operational 191
days & recharged
1,159 acre-feet ($1.4 \times 10^6 \text{ m}^3$)

In-Channel Maintenance Considerations

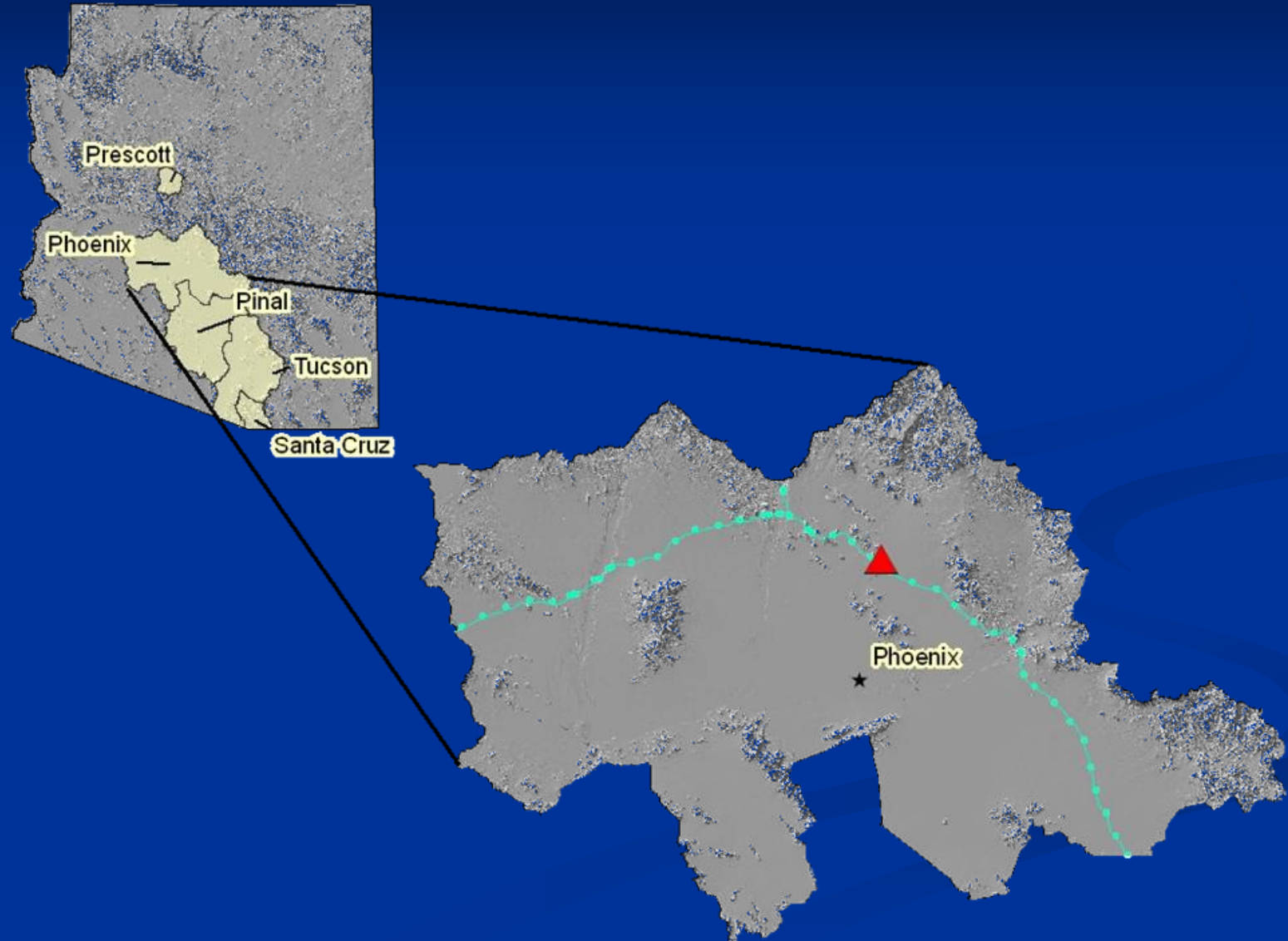
- 💧 Facility maintenance dependent on flood flows
- 💧 Difficult to maintain constructed features during high flow events
- 💧 Maintenance costs and down time can be high for in-channel projects with constructed features

Constructed USFs

Vadose Zone Recharge Well Projects

- 💧 Lower start-up costs
- 💧 Small geographical footprint
- 💧 Variable and lower recharge rates
- 💧 10 vadose zone well recharge projects statewide

City of Phoenix-Cave Creek USF

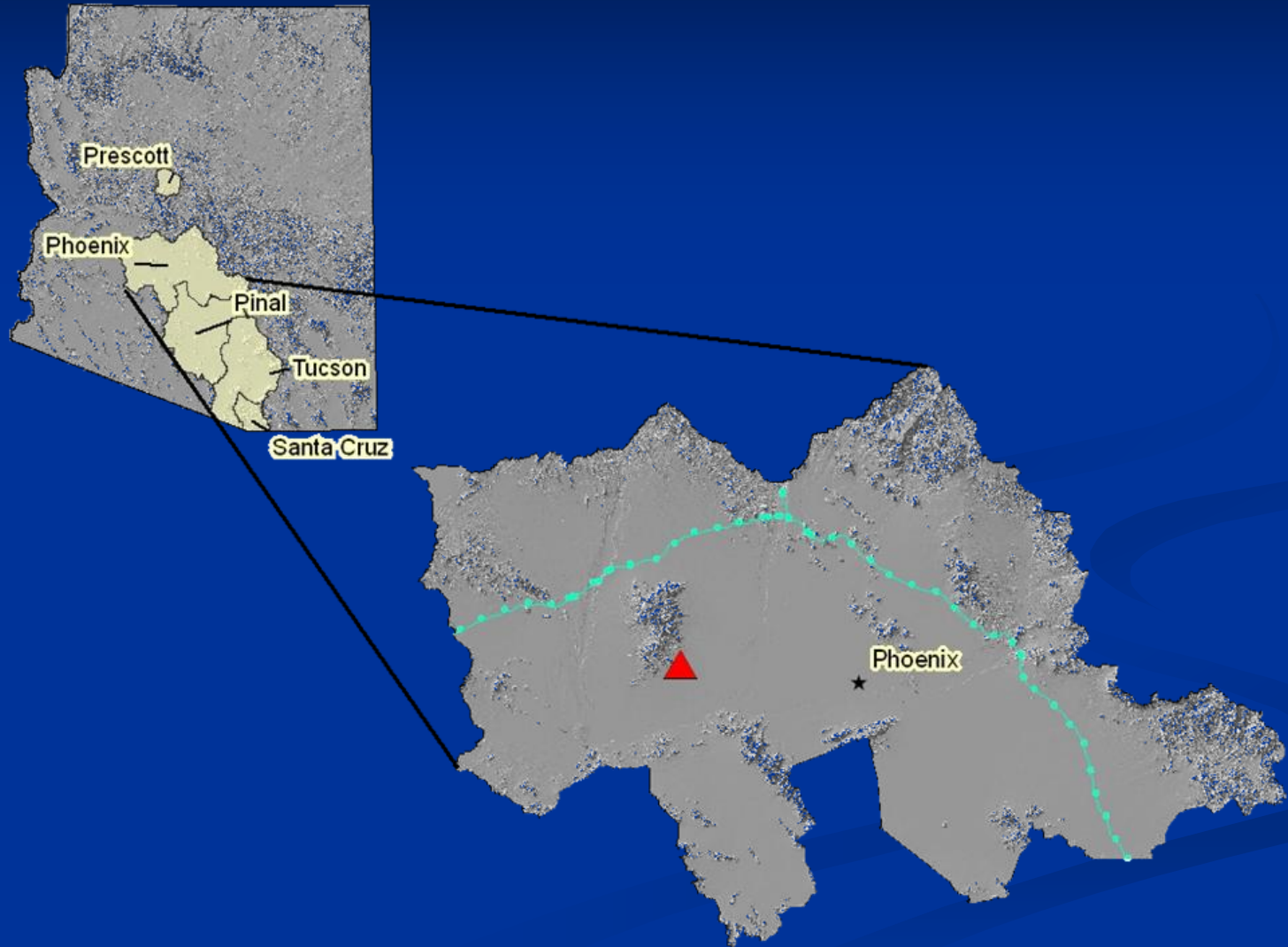


City of Phoenix-Cave Creek USF

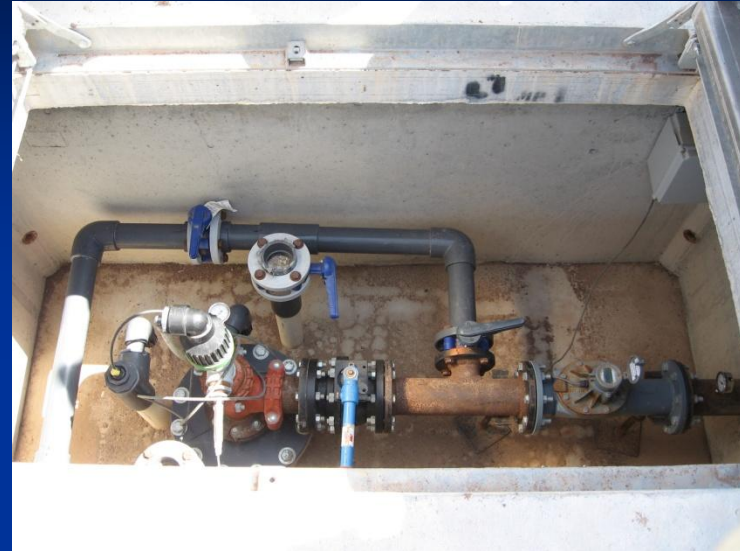
- 💧 8,961 acre-feet/year
- 💧 Effluent source water
- 💧 7 vadose zone wells
- 💧 Wells located within reclamation facility, wells exposed at surface
- 💧 2007 recharged 617 acre-feet
- 💧 Moving towards ASR for future recharge



Verrado USF



Verrado USF



- 💧 **$6.0 \times 10^5 \text{ m}^3$ /year (500 acre-feet/year)**
- 💧 **Effluent source water**
- 💧 **2 vadose zone wells**
- 💧 **Recharge Began in April 2007**
- 💧 **Wells located within a neighborhood, wells installed within secure vault for protection**

Vadose Zone Well Maintenance Considerations

- 💧 Low maintenance
- 💧 Ability to clean wells with harsher chemicals – no direct interaction with the aquifer
- 💧 Difficult to rehabilitate wells – replacements typically necessary
- 💧 Source water must have highest standard of quality (biologically and total dissolved solids)

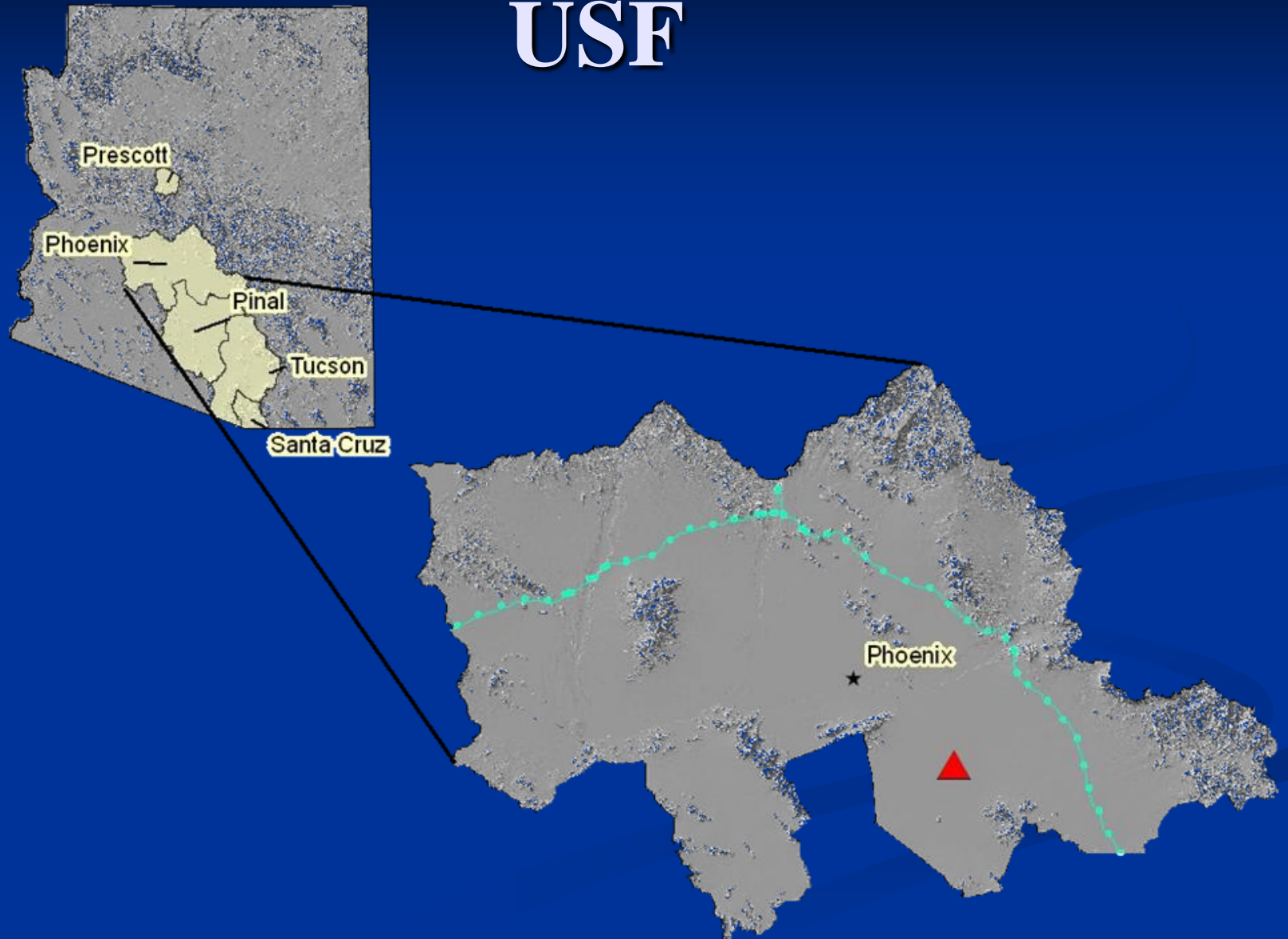
Constructed USFs

Aquifer Storage and Recovery (ASR)

Recharge Wells

- 💧 **Small geographical footprint**
- 💧 **Recharge/Recovery from same well**
- 💧 **High initial and on-going costs**
- 💧 **Variable recharge rates**
- 💧 **Direct interaction with the aquifer**
- 💧 **8 ASR well recharge projects statewide**

City of Chandler Tumbleweed USF



City of Chandler Tumbleweed USF



- 💧 11,200 acre-feet/year
- 💧 Effluent source water
- 💧 Currently 3 ASR wells
- 💧 Enclosed in large well house
- 💧 2007 recharged 3,341 acre-feet

Fountain Hills USF



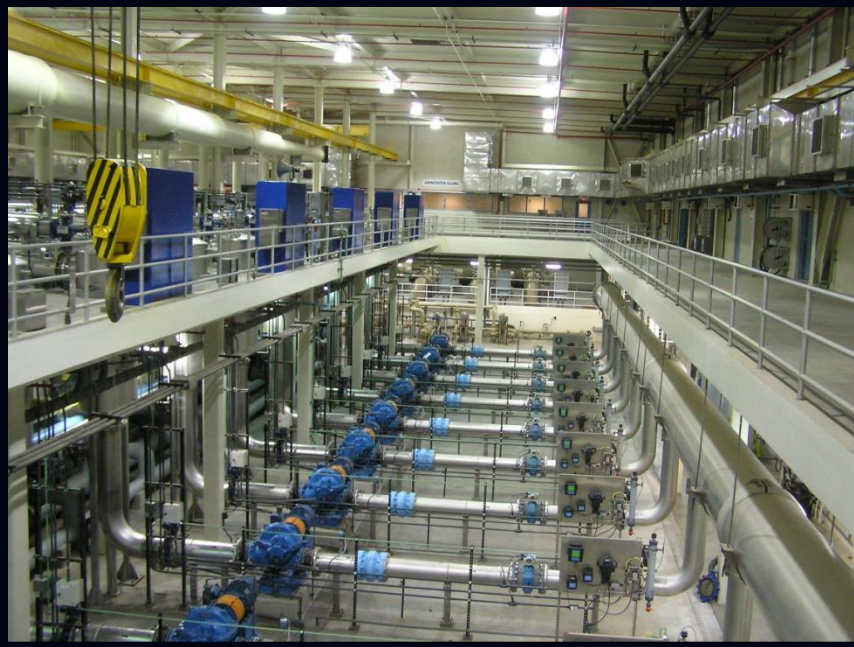
Fountain Hills USF



- $2.7 \times 10^6 \text{ m}^3 / \text{year}$ (2,241 acre-feet/year)
- Effluent source water
- ASR wells penetrate thick clays in the vadose zone recharging directly into the lower aquifer
- 4 ASR wells
- Wells installed in underground vaults to prevent public access
- 2007 recharged 647 acre-feet

ASR Maintenance Considerations

- 💧 High maintenance requirements
- 💧 Careful consideration needed when using cleaning chemicals due to direct interaction with aquifer
- 💧 ASR can inject and recover, so flushing possible
- 💧 Highest quality of source water required (biologically and total dissolved solids)



Q & A Break

Constructed USFs Recharge Basins

- 💧 High recharge/infiltration rates possible
- 💧 Basic methodology
- 💧 Large land requirement/geographical footprint
- 💧 Potential higher costs due to land acquisition
- 💧 30 recharge basin projects statewide

Town of Gilbert Riparian



Town of Gilbert Riparian

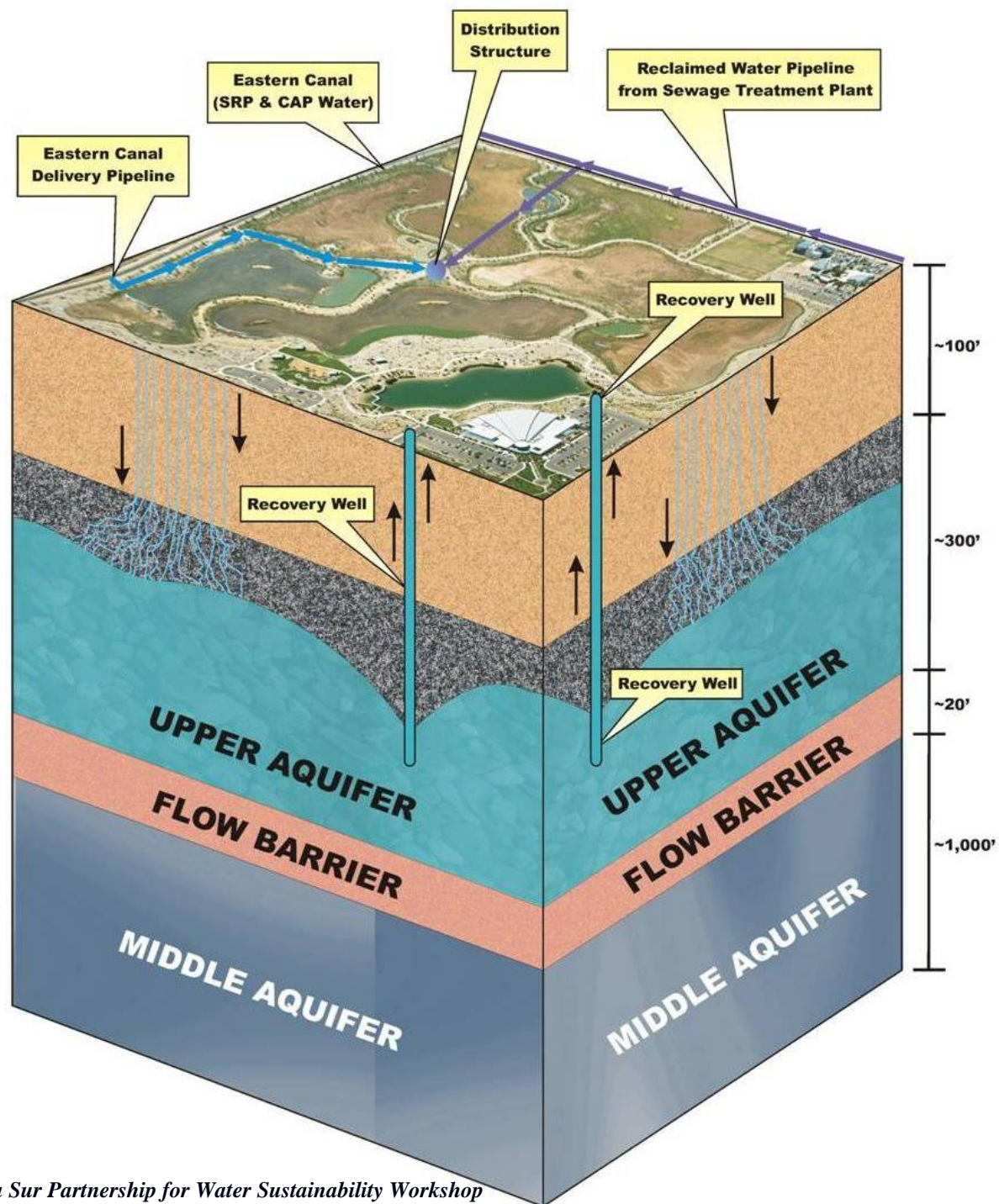


Multiple Use Facility

- Recharge
- Public
- Wildlife Preserve

- 4,369 acre-feet/year
- Effluent and Surface Water
- 2007 recharged 2,750 acre-feet



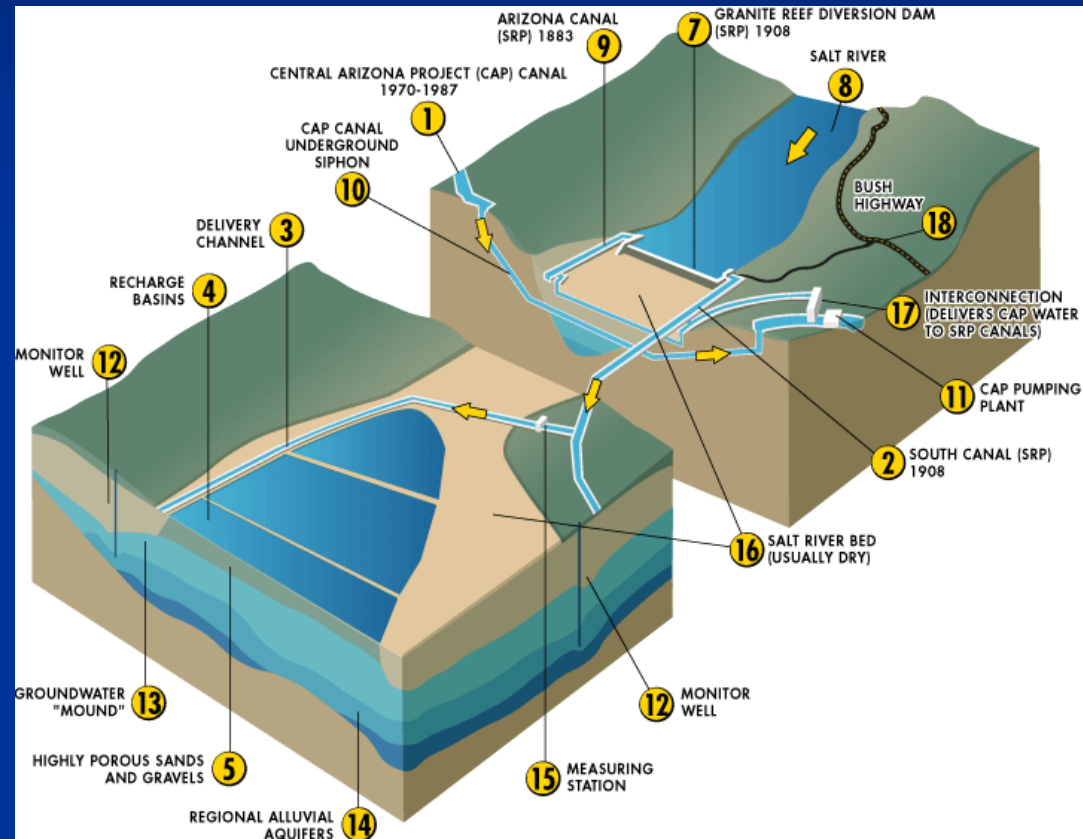


Granite Reef Underground Storage Project USF



Granite Reef Underground Storage Project USF

- One of the oldest USFs
- Permitted volume 200,000 acre-feet/year
- CAP and surface source waters
- Adjacent to Salt River channel
- 2007 recharged 51,100 acre-feet



Tonopah Desert USF



Tonopah Desert USF

- 💧 Phased permitted volume, 150,000 acre-feet maximum
- 💧 $> 0.8 \text{ km}^2$ (200 acres) of recharge basins
- 💧 CAP source water
- 💧 Avg. infiltration rate = 1.5 m/day (5 ft/day)
- 💧 2007 recharged volume 143,200 acre-feet



Photo courtesy of CAWCD

Tonopah Desert USF

- 💧 Extensive feasibility study conducted
- 💧 First year recharged ~ 130,000 acre-feet
- 💧 Nitrate flushing
 - ✦ GW above MCL after 2 months of recharge
 - ✦ Maximum nitrate level = 84 mg/l
- 💧 Infiltration/Evaporation rates
 - ✦ Infiltration rate range 1.5 to 3.8 m/day (5 to 12 feet/day)
 - ✦ Evaporation 0.5% of recharge volume

Central Avra Valley Aquifer Storage and Recovery Project USF



Central Avra Valley Aquifer Storage and Recovery Project USF

- 💧 100,000 acre-feet/year
- 💧 CAP source water
- 💧 11 recharge basins totaling > 300 acres
- 💧 “Put and take” facility
 - ✦ ~30 wells located within 1 mile of facility used for annual recovery
- 💧 2007 recharged 79,051 acre-feet



Photo courtesy of Tucson Water

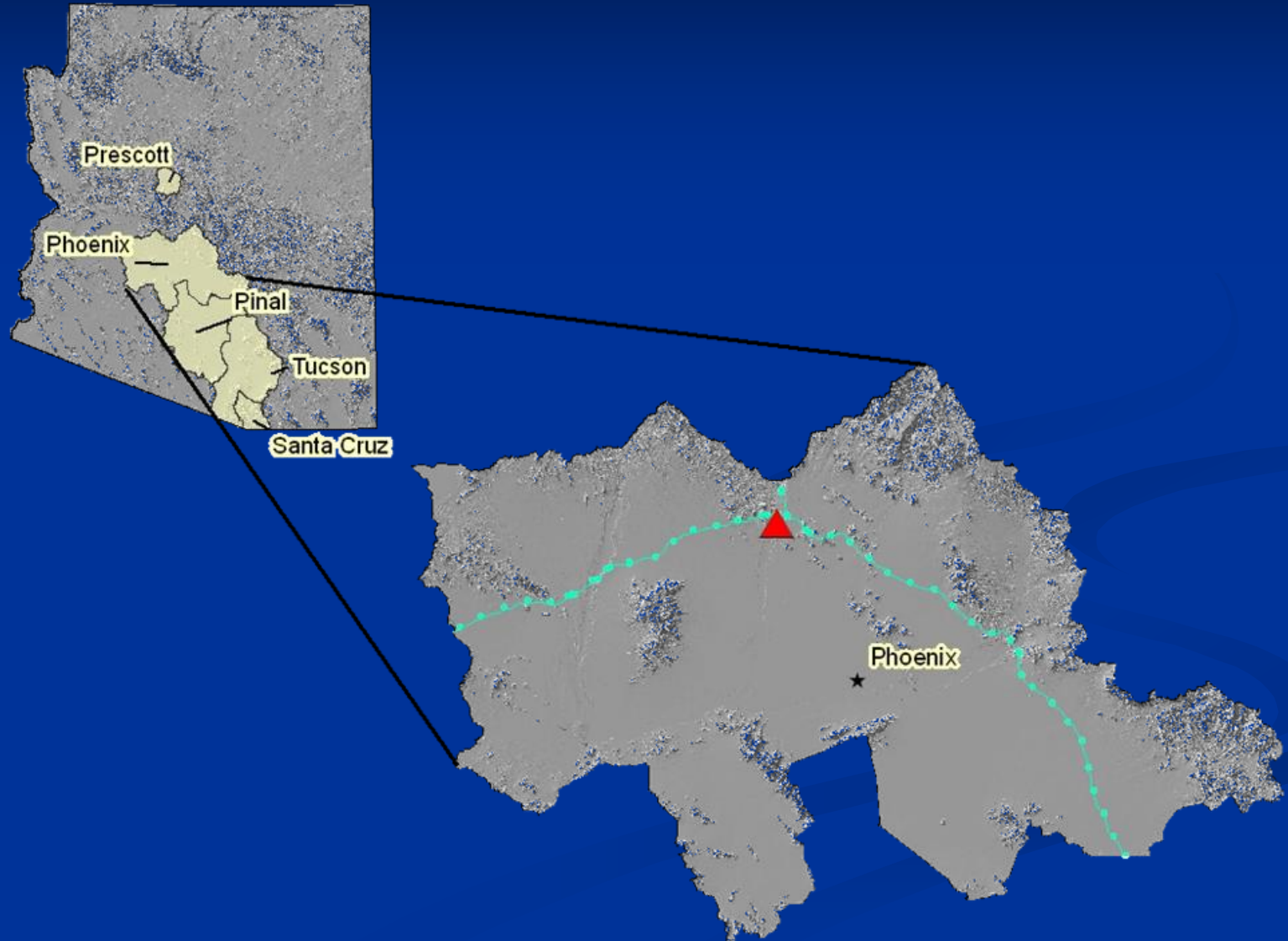
Basin Maintenance Considerations

- 💧 Basin rotation
- 💧 Scraping
- 💧 Algal growth
- 💧 Vegetation control
- 💧 Biological Fouling

Combined Recharge Methodologies

- 💧 Use of multiple facility types and recharge methodologies
- 💧 Built in contingency plan
- 💧 Operational flexibility
- 💧 9 combination projects

Agua Fria USF

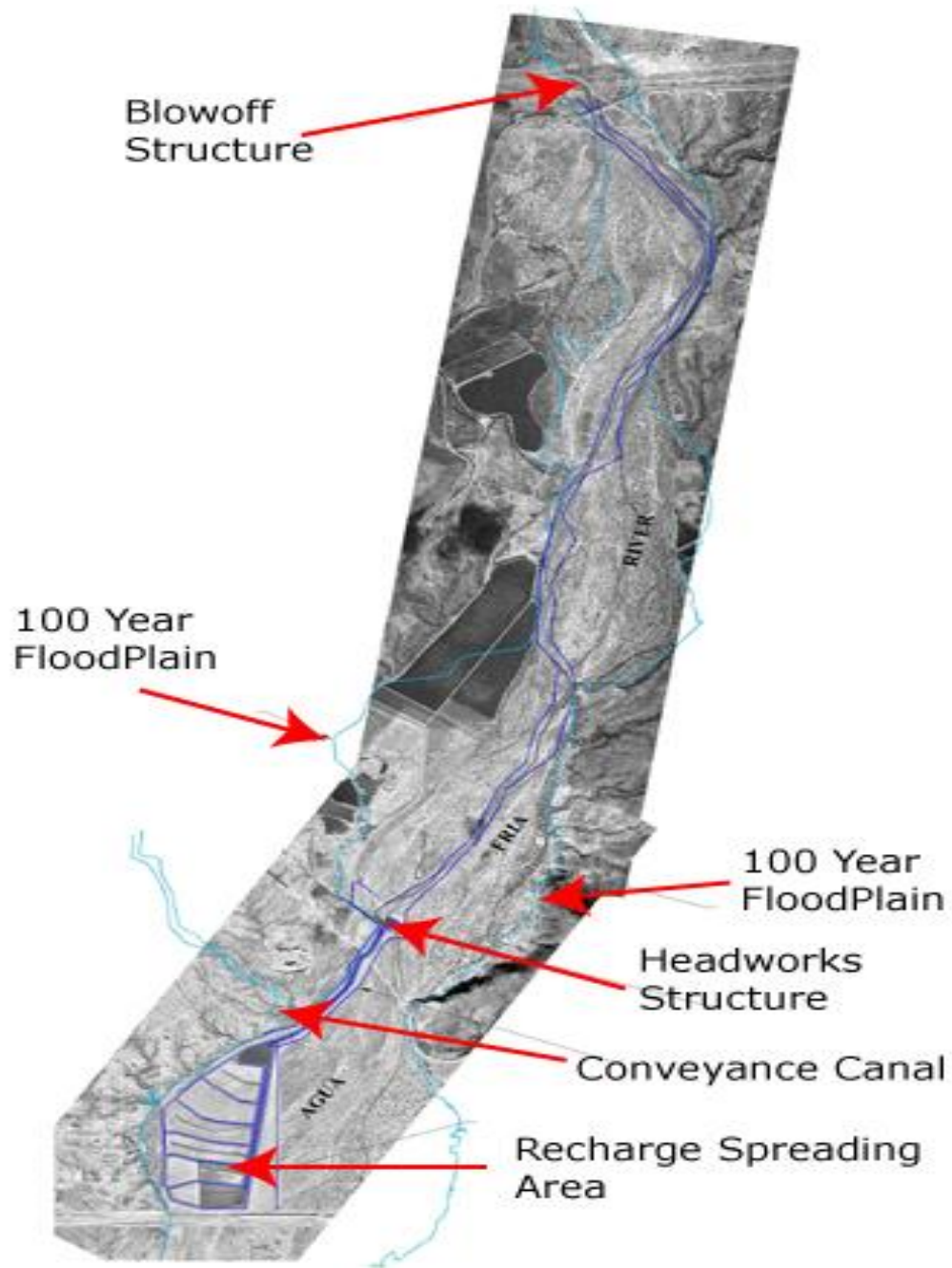


Agua Fria USF

- 💧 100,000 acre-feet/year
- 💧 CAP source water
- 💧 Managed Facility
Length ~4 mi
- 💧 Constructed Facility
7 basins with ~104 acres
- 💧 Located in Agua Fria
River channel
- 💧 2007 recharged 11,729
acre-feet



Photo courtesy of CAWCD



Superstition Mountain Community Facility District #1 USF



Superstition Mountain Community Facility District #1 USF

- 💧 $2.8 \times 10^6 \text{ m}^3 / \text{year}$ (2,352 acre-feet/year)
- 💧 Effluent source water
- 💧 10 recharge basins & 2 vadose zone wells per basin
- 💧 2007 recharged 1,463 acre-feet



Superstition Mountain Community Facility District #1 USF



Trends for Arizona Recharge

- 💧 **Effluent source water projects**
- 💧 **Smaller volume projects with combined methods**
- 💧 **Land use limitations**
- 💧 **Recharge needed for future development**
- 💧 **Water quality concerns**

Managed Aquifer Recharge integrated within an urban landscape



Arizona's Football Stadium

Basin Recharge Facility

Photo courtesy of SRP

Arizona-Baja California Sur Partnership for Water Sustainability Workshop

Managed Aquifer Recharge Outside of Arizona

- 💧 Chad, Africa
- 💧 Everglades, Florida, USA
- 💧 West Basin, California, USA
- 💧 Orange County, California, USA

Chad, Africa



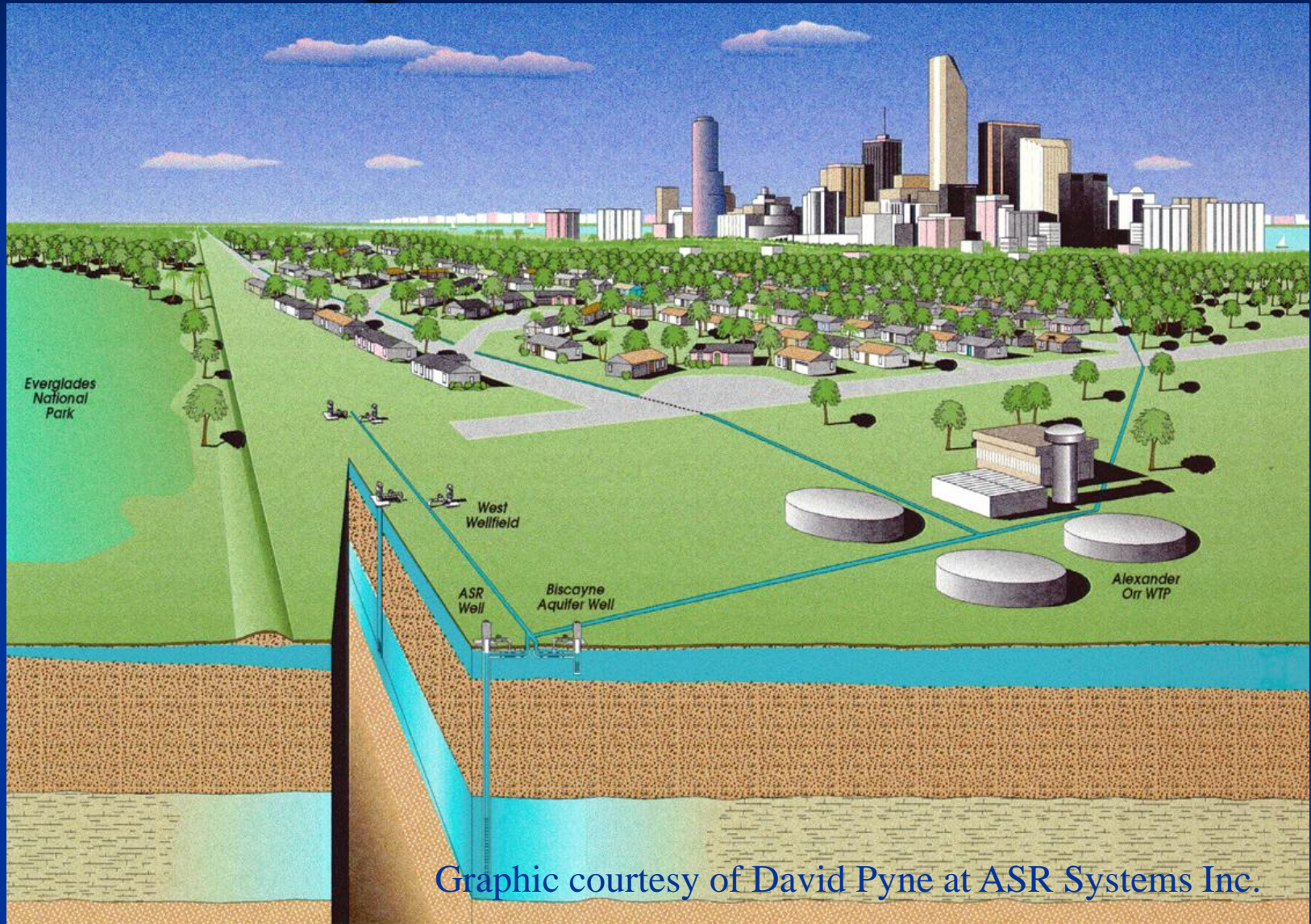
Chad, Africa



Chad, Africa



Everglades, Florida ASR



Graphic courtesy of David Pyne at ASR Systems Inc.

West Basin, California

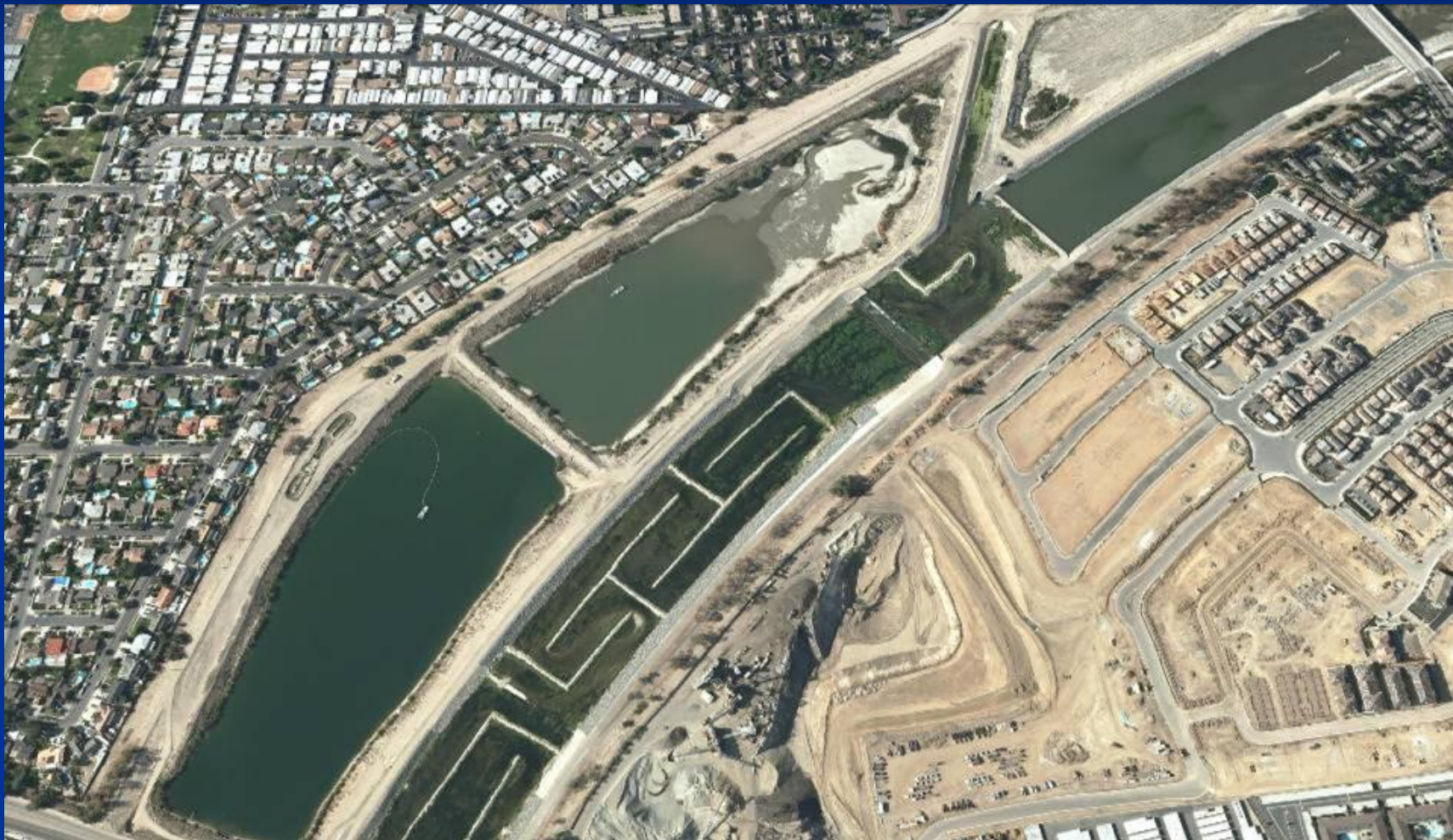
- MF/RO
- AOP
- Five Different Water Qualities for Different End Uses



Orange County, California



Orange County, California



Reclaimed Water: Planning Considerations

- 💧 Integrated Water Resources
- 💧 Watershed or Groundwater Basin Perspective
- 💧 Environmental Impacts
- 💧 Water Rights
- 💧 Economic Impacts
- 💧 Cost of Alternatives
- 💧 Water Quality
- 💧 Hydrogeology
- 💧 Public Participation and Acceptance

How Recharge Fits In to Reuse

- 💧 100% Direct Reuse is Not Easily Accomplished

- 💧 Recharge

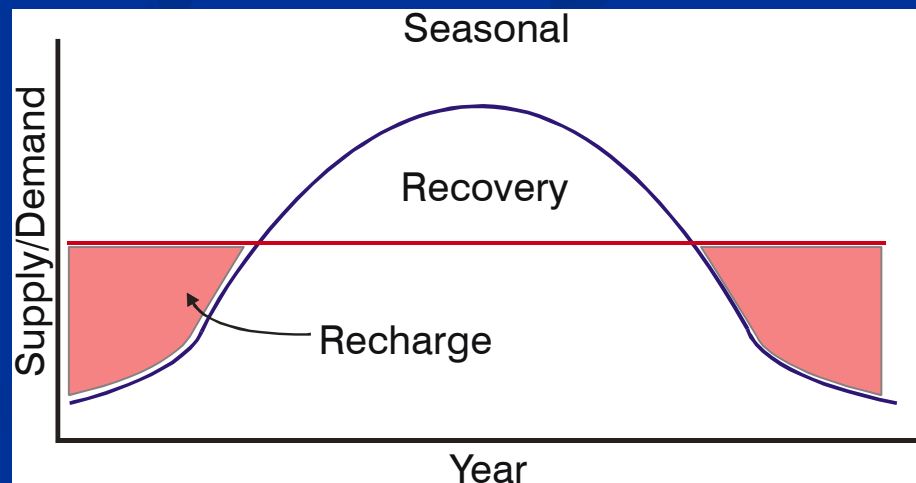
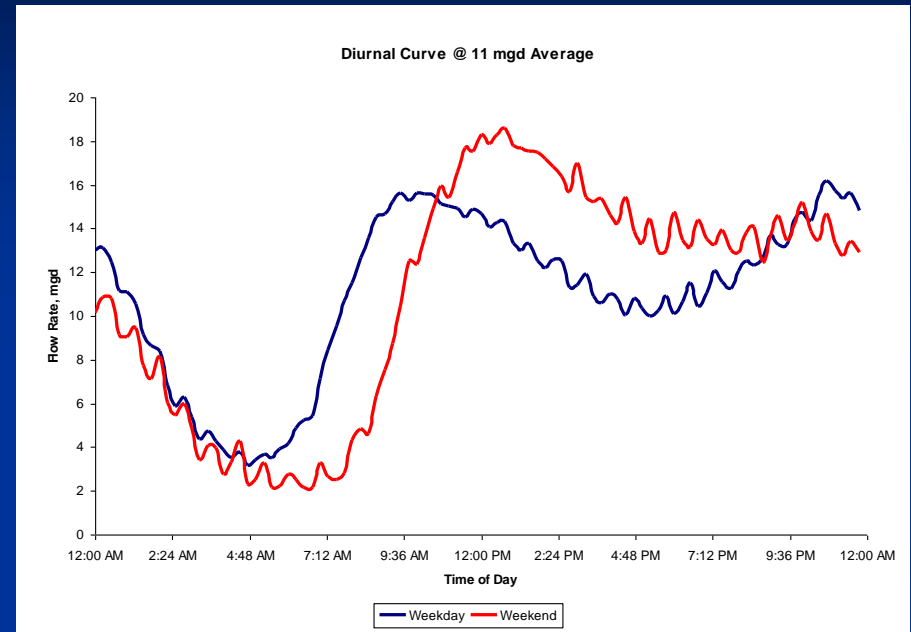
 - ✦ Seasonal & Daily Peaks

 - ✦ Reclaimed Distribution Restrictions

- 💧 Recover (Well Pumping)

 - ✦ Use of Existing Well Infrastructure

 - ✦ Use for potable & non-potable purposes

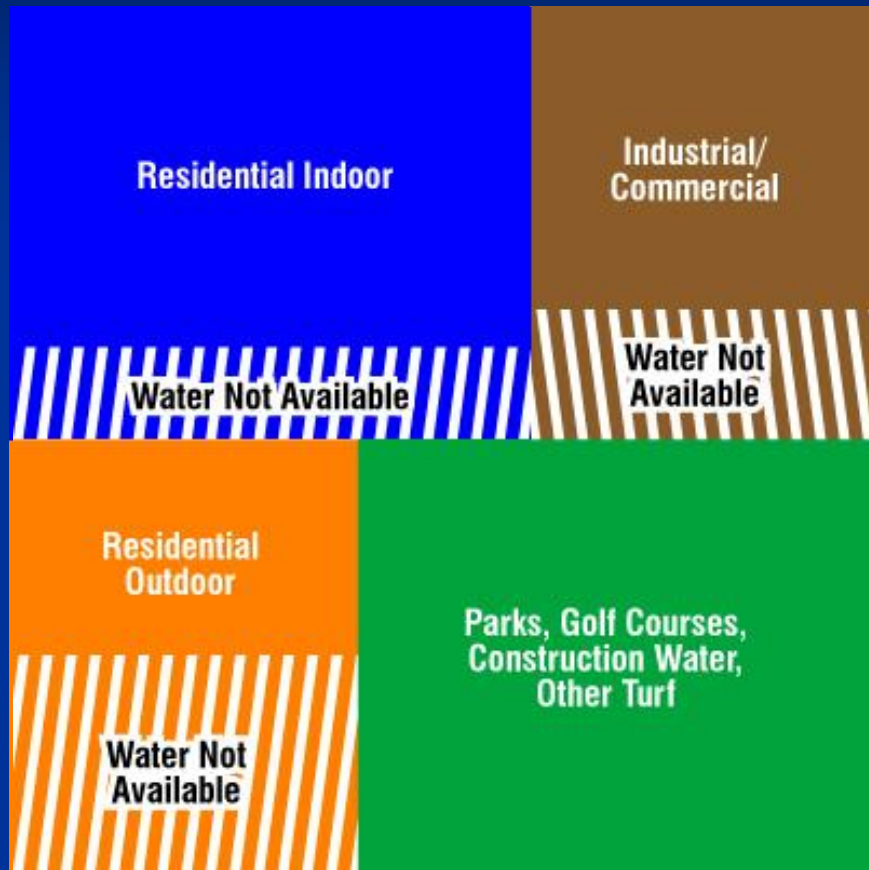


Reclaimed Water Planning Considerations



- 💧 Represents Water Use in a Community
- 💧 No drought; plenty of water for everyone
- 💧 Reclaimed water being used on green area

Reclaimed Water Planning Considerations



- 💧 Represents Water Use in a Community
- 💧 Drought occurs; water reductions
- 💧 Reclaimed water being used on green area
- 💧 Parks, golf courses, turf, etc. stays green because all reclaimed water being used there
- 💧 Political problem

Reclaimed Water Planning Considerations



- 💧 Represents Water Use in a Community
- 💧 Drought occurs; water reductions
- 💧 Reclaimed water being used on green area
- 💧 Reclaimed water also used for exchanges and recharge
- 💧 Water stays with highest and best uses

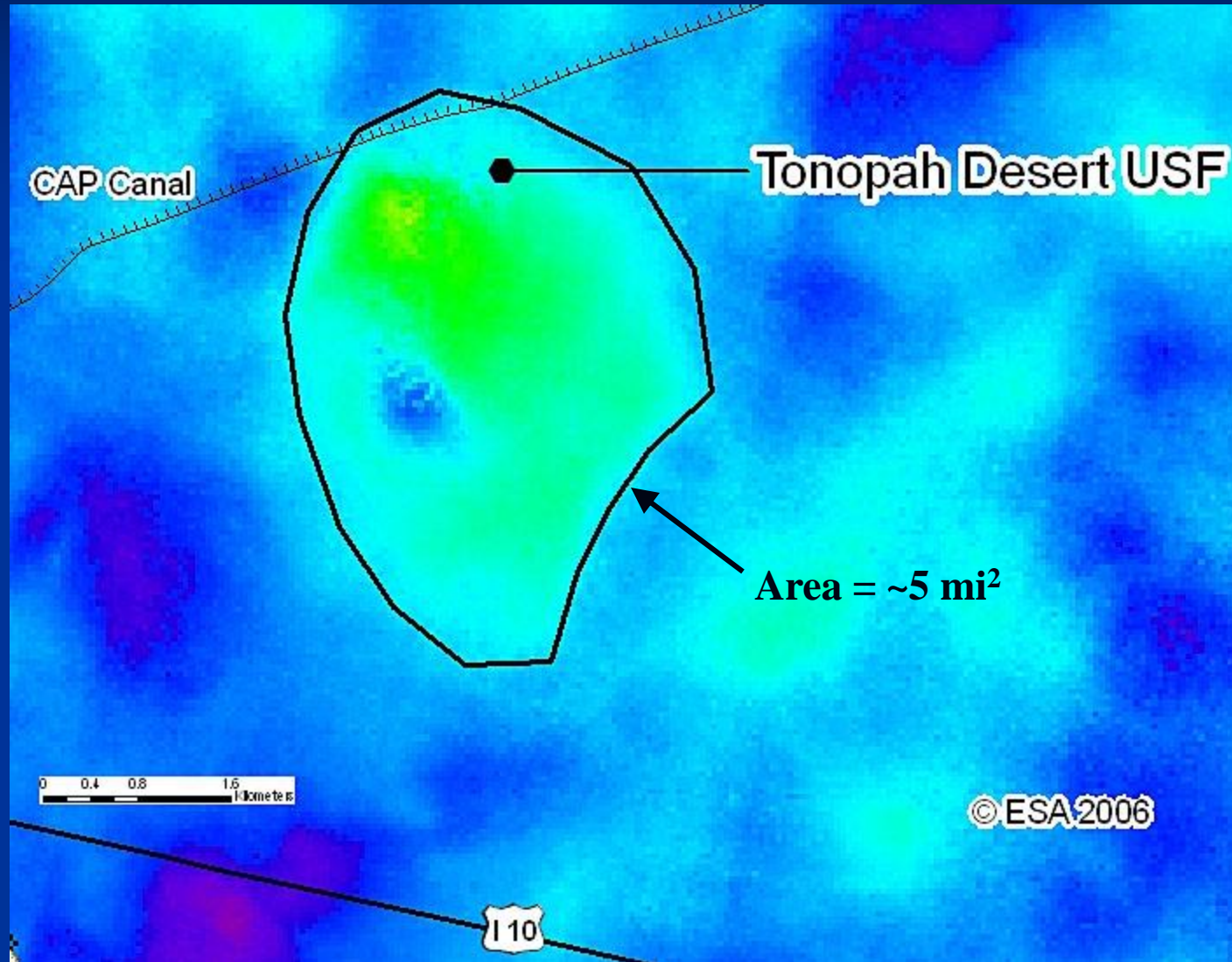
Management Tools

- 💧 **Annual reporting (regulatory requirement)**
 - ✦ Loss Calculations (evaporation and evapotranspiration)
 - ✦ Systems losses (other)
- 💧 **Water level monitoring**
 - ✦ Alert Levels and Operational Prohibition Levels
- 💧 **Water quality monitoring**
- 💧 **Equipment and USF maintenance (wells, dikes, etc.)**
- 💧 **Delivery Systems**
- 💧 **Clean Water Act (Section 208 – water quality management plan)**
- 💧 **Aquifer protection permit**
- 💧 **InSAR (new technology)**

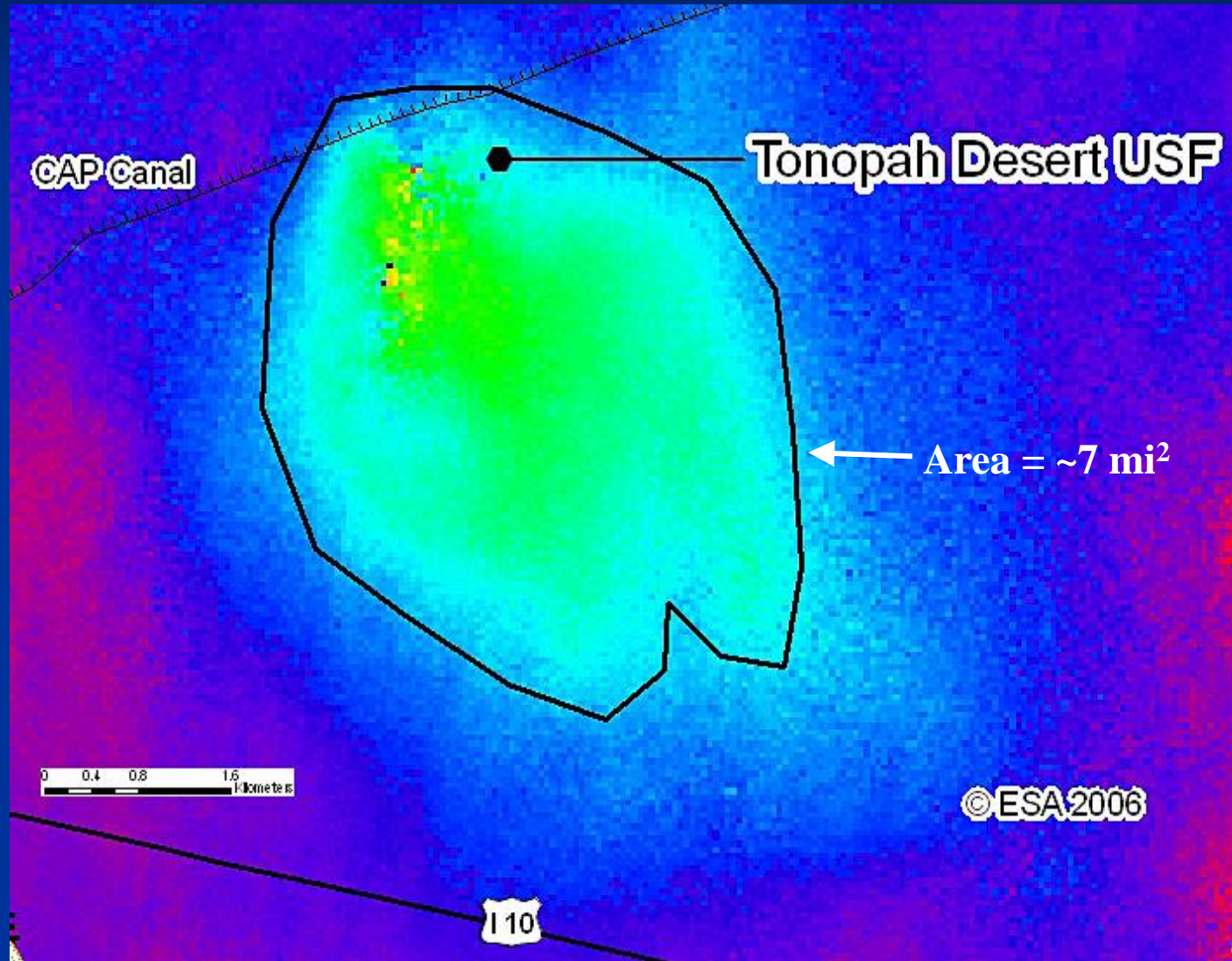
InSAR

- 💧 **Interferometric Synthetic Aperture Radar**
- 💧 **Satellite based radar imaging system**
- 💧 **Measures land surface deformation**
- 💧 **Tonopah – ~1.6 cm of land surface uplift for first year of operation; to date a total of ~2.2cm**

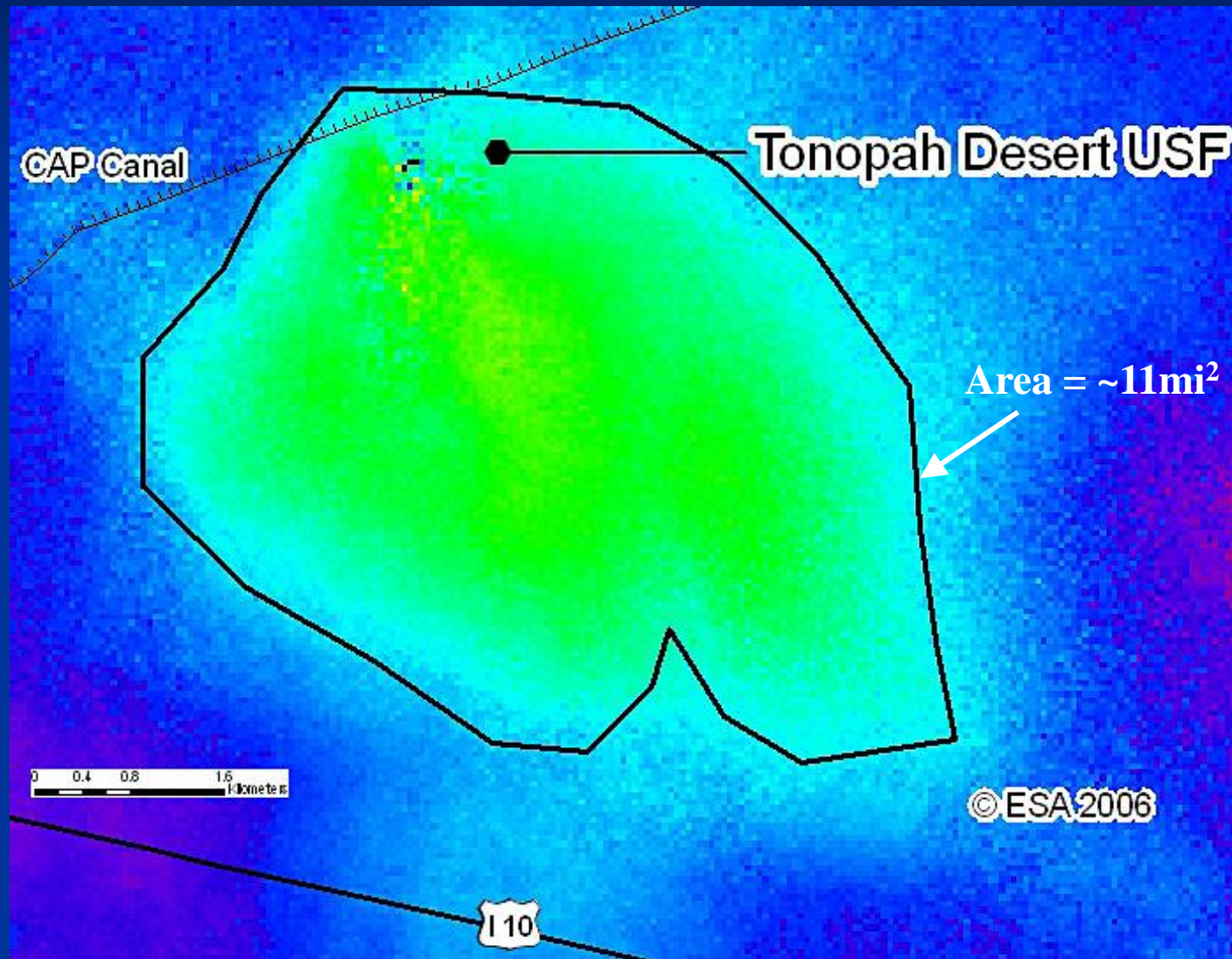
Tonopah InSAR After 6 Months



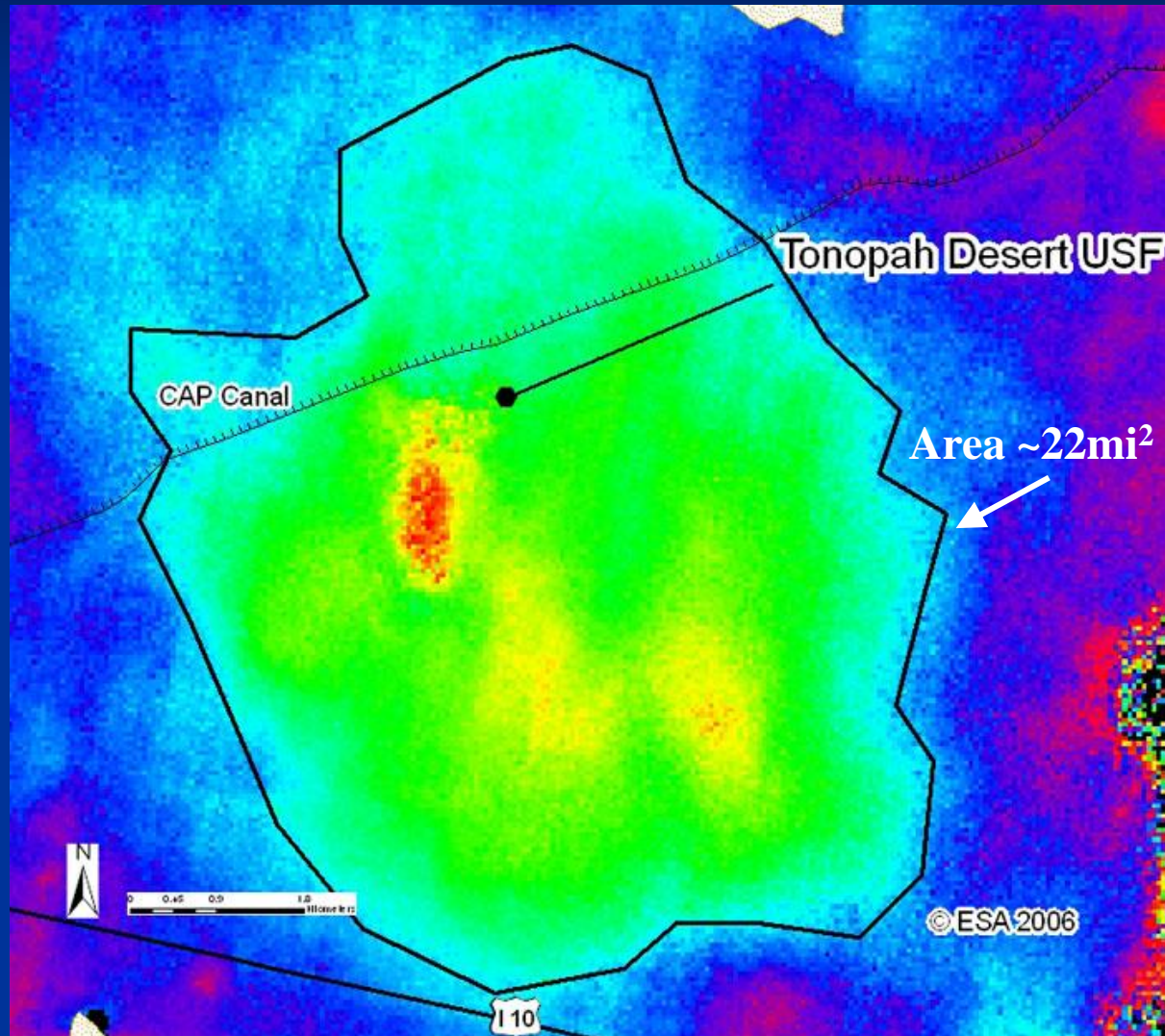
Tonopah InSAR After 10 Months



Tonopah InSAR After 12 Months



Tonopah InSAR After 19 Months



Conclusions

- 💧 **Many MAR methods**
- 💧 **Holistic water management tool**
- 💧 **Sustained water availability to meet current and future needs**
- 💧 **Analysis of available resources to develop comprehensive water management plan**

Questions?

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Special Thanks to:

